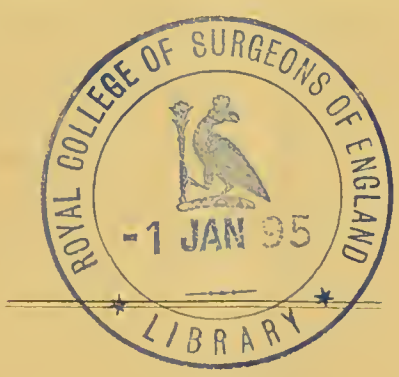
WATER-SUPPLY.

PRIZE ESSAY.

BY

THE REV. J. CLUTTERBUCK.



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WATER-SUPPLY.

All water-supply, whether surface or subterranean, whether naturally issuing aboveground from springs, or artificially reached by wells or shafts, is derived from the rainfall. Therefore, in treating of the possibility of improving the water-supply in rural parishes for agricultural and domestic purposes, the question resolves itself into the economical use or application of quantities which vary, but of which the amount may to a certain extent be ascertained. The amount and distribution of rainfall yearly attracts more attention, and many sources of information are open to the public. The tables of Mr. Glaisher and Mr. Symons show an increase of rainfall with the longitude westward, the influence of altitude, and other physical features; so that in some localities there is such an abundant and continuous rainfall as to exclude them from the scope of such an inquiry as this.

Though rainfall is reduced to, and treated with reference to, averages, the economical increase of water-supply has rather respect to a minimum, or to quantities, in excess at certain seasons, to be made available when the ordinary average supply falls short. Taking Mr. Symons's published averages of rainfall in England at 30 inches, by excluding all above 30 inches as beyond the limit of this inquiry the average is reduced to about 25 inches, the minimum at any place being 16·91 inches.

These facts should be noted, though the variations in the quantity that falls at any given season make it difficult to base any calculation on the gross quantity falling during the year. Subterranean water depends on the quantity percolating below a certain depth; the gross rainfall has a greater influence on surface supply. The difficulty alluded to is shown in a remarkable manner by the records of Dalton's gauge, kept by Mr. Dickinson, which registers the water percolating 3 feet below the surface. The average rainfall at the same place for 29 years was 22·5, the percolation 7·5; the 10 years ending 1863 gave 25·8 total fall, percolation only 5·9; showing that in the longer period the average summer rainfall was in arrear and that in winter was in excess, while in the shorter period the case was reversed.

It will be necessary to notice separately surface and subterranean water, The former comprehends all water retained in ponds whether natural or artificial, that received or collected from roofs of buildings, stored in tanks and the like, or water thrown from the surface of the soil; subterranean water, all that sinks below the surface, accumulates in permeable strata, and thence issues in springs where vent is given to it.

Surface-Water.

First, as to water collected from the roofs of buildings. This is obviously a simple process, requiring good and well-arranged spouting, with sufficient tank-storage. In the construction of farm-buildings where this supply is needed, it may repay the outlay to increase the area of water-catch beyond the absolutely necessary extent of roofing, and to adopt the covering from which rain-water is most readily and copiously thrown. Thatched roofs are beyond the scope of any calculation. Zinc, iron, lead, or any metal, slates, hard-burned Staffordshire tiles, will throw off the greater portion of all rainfall. Ordinary tiles, when dry, absorb a considerable amount of water: a shower represented by 3-100ths of an inch would be thrown from the surface of the first-named substances and absorbed by a tile. This would be repeated on the falling of every summer shower; and a calculation based on the known daily rainfall of the summer of 1864, allowing for only one shower on the days when rain was noted, gives for the 5 months from June to October inclusive, an aggregate loss of 1 inch of rain by the absorption of tiles, or about 25 gallons for every 100 square feet of roofing.

If we take the Flemish Farm at Windsor—which is covered with tiles—as an instance, the roofing may be estimated at 15,000 square feet; there would then be a loss of 7500 gallons of water, filling a tank 12 feet square by 8 feet deep. This may seem a trifling quantity, but it would be of great value in some places in seasons such as 1864.

In retentive soils, tanks for cottages may be made at a small cost by sinking casks into the ground, though brick-built tanks will neeessarily be cheapest in the end; this is one of the improvements in cottage homes which never should be omitted, even where well water is abundant. Open ponds, sunk into a clay subsoil, will, at certain seasons, receive the soakage from the surrounding soil; even those which are artificially puddled retain their water in a way difficult to explain when the natural evaporation and artificial exhaustion by cattle and other uses is taken into account. This phenomenon, for such it may be called, is very remarkably illustrated by surface ponds on the highest ridges of the chalk downs, known as dew-ponds.

Dew-Ponds.

These ponds are chiefly constructed on the highest ridges of the chalk range, whether in down or under arable cultivation, for the purpose of supplying water to the sheep stock during the summer months. In a known instance, the increase of these ponds on an extensive farm, high on the chalk range, has been made the subject of arrangement between a landlord and an incoming tenant, with a view to the introduction of steam-cultivation. Though careful and wide-spread inquiry, with repeated personal observation, have failed to clear up the difficulties presented by the sustained supply of water in these ponds, notwithstanding the drain on them by the daily demands of sheep and other stock, the following facts may be relied on, and will tend to show their great value to the flockmasters of a district where many breeding flocks are sustained during the summer months, when a good supply of water is essential to their well-being. Natural springs, as supplies, are out of the question on the summit of the chalk range, since the chalk water-level lies from 100 to 400 feet beneath these ponds.

The site selected is generally at the highest elevation on the ridges or spurs of the chalk hills, where they can receive no run of surface-water, though instances may be found where they are placed near roads on hill-sides, and so receive the run after heavy rains; of the former alone here it is proposed to speak, as they present phenomena not easily accounted for by recognised physical causes.

These ponds are constructed by persons of experience and skill. At the spot selected an excavation is made in the surface of the chalk, either round or rectangular, from 30 to 40 feet or more in diameter, from 4 to 6 feet deep. The bottom, of a basin shape, is covered in portions with clay carefully tempered, mixed with a considerably quantity of lime to prevent the working of the earth worms. As the portions are finished they are protected from the action of the sun and atmosphere by a covering of straw; when the whole bottom of the pond is so covered with an efficient and impermeable coating or puddle, a layer of broken chalk is placed upon it to prevent its injury by cattle or other means. Their cost varies from 30*l.* to 50*l.* When all is finished, water is introduced by artificial means. If there is a fall of snow, this is collected and piled up in the pond, as the readiest and least expensive method of accomplishing the object. During the falling of the snow in January, 1865, with a strong wind blowing, flaked or wattled hurdles were so placed that the drifting snow accumulating against them readily filled a pond on one of the highest ridges of the chalk range of hills. Ponds so constructed

and filled have been known for periods of twenty or thirty years never to become dry; the summer of 1864 was a notable exception, in which, during the months of April, May, June, July, and August, a less quantity of rain fell in the neighbourhood in question than for the thirty years preceding, and dew was noted deficient. A calculation, based on carefully obtained facts, shows that in 40 days, ending July 14th, 1864, a pond lost (by measurement of its surface and depth) 13,500 gallons of water; adding the known rainfall, 0·9, on the slopes and surface of the pond—1800 gallons—we have a total of 15,300. Calculating the consumption of a flock of sheep, 500, at ½ gallon per head per day; the quantity used by cottagers at 600 gallons; the evaporation, as tested by experiments, at 9000; the sum stands thus:—

Water lost by pond	13,500	15,300
Rainfall	1,800	
Consumed by Sheep	10,000	19,600
Cottages	600	
Evaporation	9,000	
Not accounted for		4,300

It is believed that ½ a gallon per day does not represent sufficient water for each sheep's consumption. It was found that a flock of ewes on dry food consumed 10 pints, or 1¼ gallon per day, in the winter of 1864-5. Taking only ¾ of a gallon, the consumption would be equal to the whole loss. The concurrent testimony of many shepherds bears out this supposition.

Apart from all such calculations, shepherds say that they see vapours gathering over the ponds; and a person of undoubted intelligence assured the writer that he has seen the vapours drawn to the ponds, as to a centre, when unmoved by wind. It is readily acknowledged that this subject requires further investigation; but, as a fact, the value and endurance of the supply to these ponds can hardly be denied. In many parts of the chalk range—especially where partially covered with woodlands—these ponds are not known, and here they might be profitably introduced; and it is believed that they would be found valuable on all high and exposed districts where summer supplies of water are needed.

The collection of surface-water from drains in *a clay subsoil*, even where the contour of the ground favours such an arrangement, must be precarious. These drains do not run except after heavy rainfalls; ponds which retain their water during a long period might be filled by these means, but, in the absence of supply from land or other springs, the quantities so stored would be likely to fail.

Pumping water from a stream would seem to be too obvious a remedy to need much notice; yet I may state that a large mansion, tenanted by several families in succession, lost its tenants for lack of good water-supply: until at length, under the advice of the writer, an effectual remedy was found by raising a supply through filtering-beds into a tank from an adjacent and frequently turbid stream.

Land-Springs.

Land-spring is a term generally applied to sources of water which are found in or flow from superficial beds of gravel or drift, lying on an impervious substratum. Since many districts throughout England are entirely dependent on such sources for their supply of water they require further notice. Very many of our most ancient towns and other places of early habitation are placed on drift-gravel, probably from the facility with which water is thence obtained. The older part of London, and the city of Oxford, on different geological formations, are noteworthy examples of towns so supplied, until they were extended beyond their ancient limits, or until these sources, as is often the case, became tainted by infiltration from sewers, cesspools, and the like. Most of the higher ground on the London clay, such as Hampstead, Highgate, Harrow, Bushey Heath, and the Bagshot district—where a better-defined formation overlies the London clay—are examples of this kind of supply. In the Bagshot sands, in consequence of their great depth and wide development, by taking advantage of the levels at which water is thrown out by bands of clay alternating with the sand-beds and by turning to account the undulations of surface, large lakes or ponds are formed, such as Virginia Water. At Bear Wood, a dam being thrown across a valley, the water collected in an ornamental lake serves to drive the agricultural and other machinery of the Home Farm,—an example of economising waste water which is worthy of especial notice. In the London and Hampshire Basins this character of supply is not entirely confined to the limits of the London clay *in situ*, but extends to the higher ridges of the chalk, which are frequently capped with traces of the tertiary formations, so that water is frequently retained in gravels by which they are covered or upheld in surface-ponds. The chalk district is, therefore, marked by the gathering of the population either on these higher levels or else in the valleys in which run the streams which issue from the subjacent chalk stratum. In the former of these a rigid economy in the use of water is forced on the agricultural and other population, as, on the failing of the supply, no resource is left but the streams in the valleys, or very deep wells, from which water

is necessarily raised with great labour. No districts suffered more from lack of water to man and beast, during the summer of 1864, than the higher ranges of the chalk, from the failing of the dew-ponds on the downs and all other surface supplies. The failure being due to the quantities actually drawn from them suggests an increase in the number of these ponds, or their adoption in localities where they have not been tried, especially where they would be easily formed in the tenacious soils found on the upper levels. There is sometimes a waste of water in these localities where it might be turned to good account. The beds of sand or gravel and the clay on which they rest, are frequently drained by means of shafts or dumb-wells, sunk through them to the surface of the chalk, into which the water freely sinks from the drains which converge to them as a central outfall. Necessary as draining is, this water might often be stored in ponds sunk through the gravel into the clay, with an arrangement of pipes to prevent its rising above a certain level, or subterranean tanks might be formed where the clay is of sufficient thickness below the gravel. Where the beds of gravel are deep and extensive, it is obvious that water may be led away from a hill-side and form a perennial stream of the greatest value.

This is well illustrated on the well-known Tiptree Hall Farm. When first occupied by Mr. Alderman Mechi, land-springs issued from the slightly-rising ground to the north of the house, the weepings of which generated a peat-bed. Deep drains were driven into the hill-side, cutting through the margin of the gravel into the clay beneath, whence so large a quantity of water was gathered into one head as to supply all the ordinary wants of the homestead, and furnish a volume sufficient to carry out at all seasons the system of irrigation coextensive with the farm, whilst its overplus carries health and comfort to a once fever-stricken district in its course below. As the utilization of this water is instructive, so in the source whence it flows a lesson may be learned as to the geological and physical conditions under which a like supply may be turned to good account elsewhere.

The village of Tiptree stands on an extensive bed of drift-gravel and sand, resting on the tertiary clay, naturally drained by streamlets which flow down the shallow valleys or depressions by which it is flanked or intersected. As in all such cases, the subterranean water is upheld in the soil at an angle above its outfall, varying with, and dependent on the closeness of the sand or gravel in which it lies. The water in the village wells stood, in the autumn of 1864, 16 or 18 feet above the artificial and ever-flowing vent given to it by Mr. Mechi's drains. It is on record that, when these drains were first dug, many, if not all,

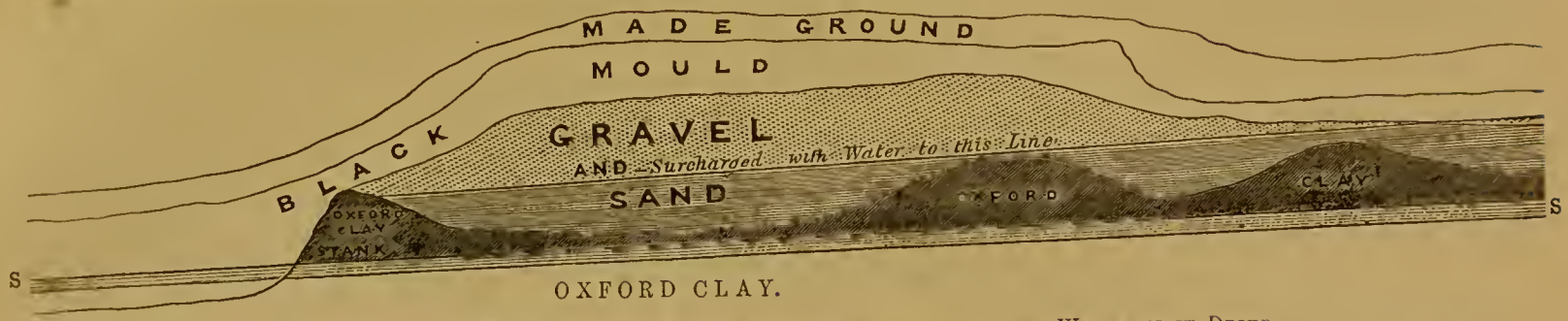
the wells in the village were more or less affected. If the supply were less, and it was necessary for the sake of Tiptree farm and establishment to economise the supply (and this may serve as a general illustration), a well (call it of depression) on a large scale might be sunk near the centre of the gravel-bed, whence the greatest body of water might be raised by artificial means, or allowed to pass by gravitation from the well to the lower levels by some simple contrivance providing for the shutting off the water at pleasure. Such sources of water, when practically perennial, are often said to yield an undeviating volume; a periodical gauging would show that the quantity is in the ratio of the natural exhaustion and replenishment by rainfall.

It should be noted that sands and gravels are speedily replenished; as gravelly soils, from their silicious and stony character, preclude such an absorption of water as takes place in loams, chalk, and other substances after a period of drought. Careful observation and frequent measurements have shown that wells in sand and gravel are replenished by a heavy summer shower; whereas it requires from 2 to 3 inches of continuous autumn rainfall to replace the evaporation of the summer in the soils of a more tenacious character.

No general rules can be laid down for dealing economically with sources or supplies of water held in drifts or gravels which flow aboveground as landsprings, unless they are founded on the ascertained geological condition, whether of the gravel-beds themselves or of the surface of the clay on which they rest.

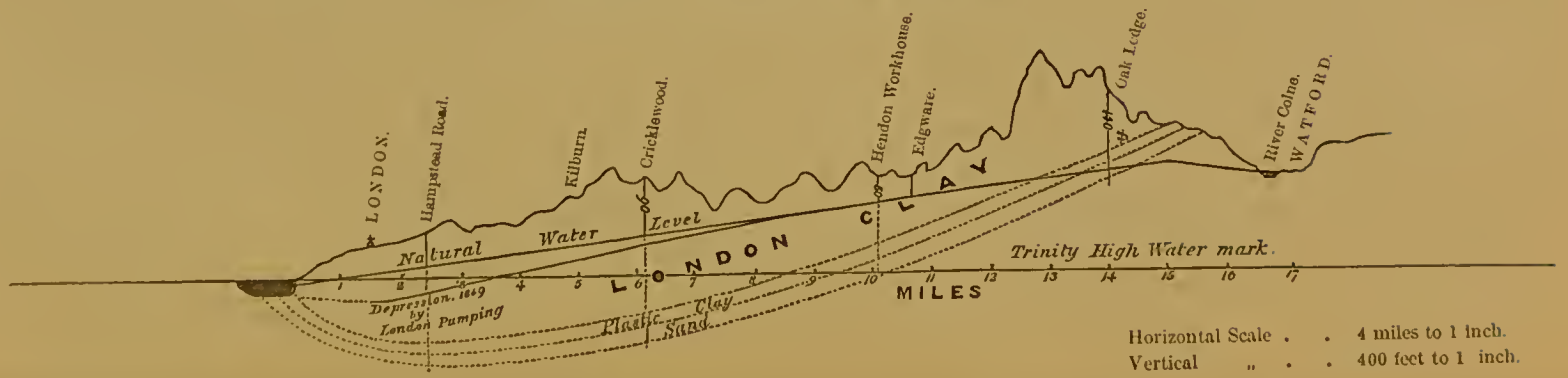
The gault, Kimmeridge, Oxford, lias, and other clays—which are of the character of marls, as in the new red sandstone—present, when their surface is exposed, a corrugated character. The Keythorpe system of drainage is based on this fact; if we may judge by the present river action on the gault in the valley of the Thames, this condition has probably a fluviatile origin. Be that as it may, the cutting through one of these subterranean stanks or ridges will often lay a large tract immediately dry. This was the case in the city of Oxford, when a system of deep sewer-drainage was attempted, by which the house-wells were laid dry through a considerable district, till the stank of clay cut through was restored by artificial means, when the water was restored also. The section, A (see next page), made at the time, is given as a good illustration. When, under such circumstances the water-level has been affected, the wells have been sunk into the subjacent clay; but the water held in the clay is often so surcharged with mineral substances as to render it unfit for use. If the water is not too much reduced in the drift, the bottom of the well should be enlarged, as a sort of subterranean tank, rather than pierce the clay under any circumstances. The surface, or

A.—SECTION OF UNDERGROUND NATURAL STANKS, OR UNDULATIONS, ON THE SURFACE OF OXFORD CLAY AT OXFORD.



(S) Sewer in Cutting of which the Gravel was Drained and the Wells in it Dried.

B.—SECTION OF THE LONDON BASIN, FROM WATFORD TO LONDON, SHEWING THE HEIGHT TO WHICH WATER RISES IN WELLS BETWEEN THOSE PLACES.



rather landspring, supplies of water are often undervalued, and great expense is incurred in sinking to deeper sources.

Artesian Wells.

Dr. Buckland, in his 'Bridgewater Treatise,' defines artesian wells as "perpetually flowing fountains, obtained by boring a small hole through strata that are destitute of water into lower strata loaded with subterranean sheets of this important fluid, which ascends by hydrostatic pressure through pipes let down to conduct it to the surface." As there are very many cases in which the water does not attain the surface of the ground, the name artesiod has been applied to such, because they do not present all the conditions in the above definition; besides which, their construction so far differs, that a shaft, as of an ordinary well, must be sunk below the level attained by the water, from which it must be raised by artificial means. All the deep wells in London are of this character.

There is a very common impression that water may be obtained in any locality by boring, if it be carried to a sufficient depth. Immense sums of money have been thrown away in such attempts, and in other cases the quality of the water when obtained renders it unfit for use. These wells should never be sunk without a knowledge of the local geological conditions on which their success depends. The most experienced geologists may be deceived by anomalous conditions of the substrata, which cannot be foreseen. It may be useful to mention some localities and strata where boring for water is most likely to succeed or to fail.

It has been ascertained that water naturally rises in these wells to the mean level between the highest source of supply and the ultimate natural outfall. This is exemplified in the London and Paris basins; the one outfall being the River Thames below London, the other the sea at or about Havre. Under London the level has been depressed to the amount of 60 feet; at Paris the famous artesian fountain of Grenelle has been slightly affected by the newly-bored well at Passy. In illustration of the former, a section, B, is given of the ascertained height to which water rises in artesian or artesiod wells on a certain line in the London basin, which, with certain modifications, will show the way in which water will rise in other localities; though, for all ordinary practical purposes, the best guide will be the known height to which water will rise in such wells where the experiment has been made. In the absence of such a guide, this may be calculated on the principle illustrated by the section. The water will be found to rise to the surface wherever the level of the surface falls below the angle described by the subterranean water-level. This, notwithstanding the unnatural depression caused by London pumping,

is the case at Tottenham, Tooting, Uxbridge, and other places. The depth to which the borings must be carried varies considerably. The subterranean geology of London and its immediate environs, as an example of the condition of the London basin extending from Essex to Hampshire, will be best understood by plans and sections published by Mr. R. W. Mylne, C.E.

Water will rise in artesian or artesiod wells throughout the London basin, where the chalk is covered by the London or plastic clays. Though ruled by various outfalls, and disturbed in some cases by faults, the height it will attain may be made a matter of calculation: the great difficulty is the thickness of the upper strata, especially where the surface of the clays rises in hills and ridges, or where they are covered by the Bagshot sands. If, by way of example, a line from Basingstoke to Colchester be taken, where at the former place the water in the chalk stands 240 feet above Trinity high-water mark; at Strathfieldsaye, $6\frac{1}{2}$ miles distant, in a well sunk by the late Duke of Wellington for the use of the villagers, 300 feet down to the chalk, the water rises to within 15 or 20 feet of the surface, which may be 150 feet above Trinity high-water mark; at Bear Wood 350 feet to the chalk, the water stands about 120 feet above Trinity high-water mark; at Cricklewood, where this line intersects that of the section given, the water is 60 feet above Trinity high-water mark and 270 feet to the chalk; at Tottenham 70 feet above Trinity high-water mark, and 140 to the chalk; at Witham (the outlay here was 150*l.*), 306 feet to the chalk, water within a few feet of the surface, about 120 feet above Trinity high-water mark; at Colchester, 143 feet to the chalk, water about 5 feet above high-water mark.

In the Hampshire basin, though geologically the same as that of London, the condition of the chalk, probably from greater disturbance, cannot be relied on as a source of supply for artesian wells. A well dug on Southampton Common to a great depth was a gigantic failure. Again, at Portsmouth Dockyard the chalk was reached at 400 feet, and pierced an additional 500 feet without success. But here considerable quantities of water are obtained for the supply of the Dockyard by boring into the beds overlying the tertiaries, a district too small to come within the scope of our subject as connected with the interests of agriculture.

Following our inquiry into the supplies to be procured by boring, according to the geological series, the next in order is the gault clay, which occupies a rather narrow slip of country, more or less, from Dorsetshire to the Wash. It is also developed in the Isle of Wight, under the Sussex Downs, and in Yorkshire. The artesian wells at Cambridge, sunk through the gault into the lower greensand, are a notable instance of success. The

water, once flowing to the surface, does not now attain that level by a few feet; their depth is said to be from 130 to 140 feet. The water from wells sunk through the gault is slightly ferruginous, as might be expected from the nature of the greensand, whence it rises. At Grenelle, where there are the same geological conditions, the water is often used for hospital purposes, and it is a practice to place glass vessels in the flowing water, where they acquire a yellow tint. As the water in the lower greensand has no defined outfall, and as the depth of the gault clay varies, no rule can be laid down. The greensand will generally be reached under 150 feet, the water will seldom rise to the surface, therefore shafts must usually be sunk, into which the water will rise. This is the case at Hinxworth, near Baldock, and many other places where the geological conditions are the same. Care must be taken not to sink for water where the lower greensand is absent, as in many parts of Oxfordshire and the Vale of White Horse. Instances of failure have occurred at Tetsworth, where the gault rests on the Kimmeridge clay.

As the gault clay underlies the escarpment of the upper greensand, or chalk, the most obvious source of water-supply to the surface of the gault is from the springs which flow from, or generally above the junction of these strata. Reservoirs might easily be formed for whole districts by the common and united action of landowners to secure water of the best quality. Water rises by gravitation from such a source to the top of Adwell House, near Tetsworth. The town of Aylesbury is now seeking such a supply from the chalk range near Tring. These valuable waters, which might in many places be far more profitably used, now run into the Ouse or the Thames.

Next in order is the Kimmeridge clay. The same hindrance as arises from the absence of the greensand below the gault is found where the Kimmeridge rests on the Oxford clay. It was by overlooking this fact that at least 2000*l.* was needlessly expended in boring a well, over 500 feet deep, at the Lunatic Asylum near Aylesbury. At Abingdon there is an instance of water obtained by boring through the Kimmeridge clay into the coraline oolite, the whole depth, partly into the latter stratum, being about 60 feet. The water is slightly impregnated with sulphuretted hydrogen and iron, which it is believed is the case elsewhere. It supplies a drinking-fountain in one of the back-streets of Abingdon.

No really successful instance of an artesian well in the Oxford clay has fallen under my immediate observation. Its widely-extended surface and position on the lower oolitic strata are physical features which point to it as lacking good water, and as likely to derive a supply by boring through it to the oolitic rock

beneath. If the well or boring were carried deep into the subjacent rock and were perpetually flowing, the water might be cleansed of its impurities; but those specimens which I have met with and tested have been hopelessly impure.

Lower in the oolitic series there are instances of successful artesian borings. Thus at Bourn, in Lincolnshire, a large supply has been obtained from borings through the Forest marble and Bradford clays, to a depth of about 90 feet, whence the water overflows the surface. The distribution and presence of these clay-beds and the frequent faults in the oolitic strata are so complicated, that it is impossible to lay down any rules for guidance.

The same may be said of the lias clays which underlie the oolitic rocks. The marlstone, generally charged with water, which intervenes between the upper and lower lias clays, would seldom yield its water except to wells sunk in the ordinary way. At Chipping Norton the lower lias clay was pierced to the depth of 500 feet, in the hope of obtaining water from the underlying new red sandstone formation: the attempt was abandoned at that depth. Again, much the same may be said of the red sandstone formation, which forms so large a part of the surface of western England, though it may and often does yield its subterranean water when deeply pierced. At York water so raised was too much charged with iron and other mineral substances to be of any real value. The well-known salt and other mineral springs in this formation point to the probability of their existence elsewhere.

As artesian wells derive their supply from deep-seated or main-springs, the existence of such sources of water has, to a certain extent, been anticipated, though it is quite necessary to speak separately of main-springs.

Main-springs.

As the term land-spring is usually applied to sources of water flowing from superficial beds of drift, sand, or gravel, resting on impervious substrata, the term main-spring usually indicates those deep-seated supplies found in the recognised geological formations, such as the chalk, greensands, oolitic, some beds of lias, new red sandstone, and any other stratum into which the water, falling on its surface, will freely sink through cracks or crevices, forming beds of water which rise in these strata till they find vent in valleys and depressions, and so form the natural perennial sources of rivers, or hidden supplies, which are reached by sinking shafts or wells, whence water is raised by artificial means.

To advance our knowledge of the presence of these supplies, the localities and depths at which they may be found, their eco-

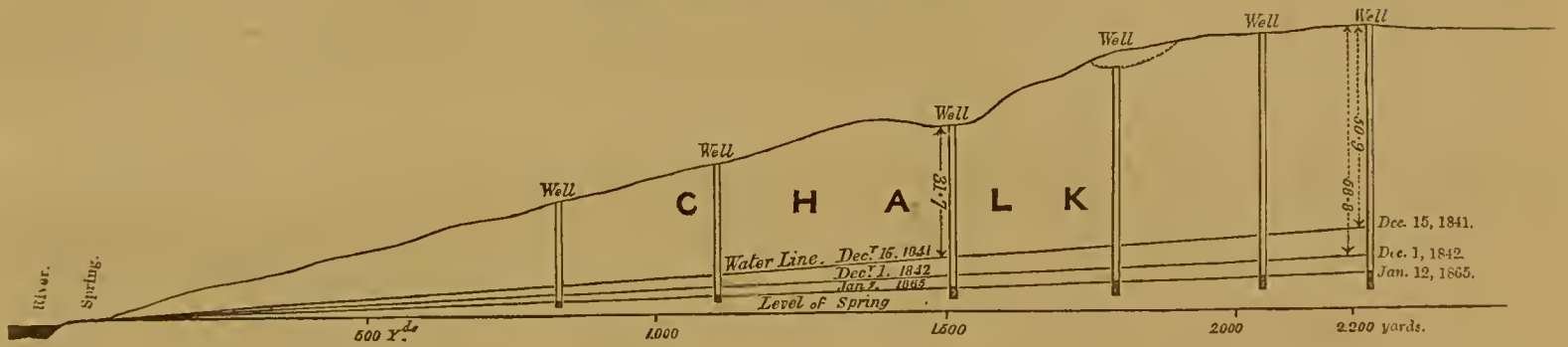
nomical use, and the means which will afford increased facilities in obtaining them, is the chief object of this communication.

The water-bearing formations above the chalk are generally of so superficial a character, and so complicated in their geological structure, that no definite rule can be laid down as to the water they contain. The elaborate Reports published by the General Board of Health on the proposed supply of water to London from the Bagshot sands in 1850, are a sufficient guide to those who wish to investigate that question. Though these sands in some localities are of considerable thickness, and from the alternation of the sands with clay beds throw out water at various levels, they very often represent sources of land-springs.

The *chalk formation* occupies a large surface of the east and south of England, and may be said (if we include the tertiary-beds by which it is partially covered) to extend from the Chiltern range to the German Ocean. This is the chief source of the water supplied to the Thames and many other rivers. The water falling on its surface where exposed, or where covered with pervious beds of gravel, sinks into this stratum and forms a subterranean bed of water, the surface of which has been called the chalk-water level. The depth at which water may be reached in the chalk may be made a matter of calculation. Take the level of any known spring or outfall, and then allow for an inclination of 10 feet per mile at least as the inclination of the water-line, it will be found that the surface-line of the subterranean water dips towards its nearest vent, the angle of inclination being ruled by the friction or resistance encountered by the water in its passage through the stratum. As the subterranean supply is replenished, this line will rise at an angle increasing with its distance from the vent.

A section, C (see next page), based upon absolute measurement and frequent observation, through a long period, is given to illustrate this phenomenon. If the level of water in two wells situate in a line to the outfall be ascertained, the water will be reached in a well to be made midway between them at the mean depth of the two; and this will be true of all wells sunk in any water-bearing stratum at all like the chalk. The raising of water from the chalk in the upper levels, where the water-level lies 300 or more feet below the surface, must be laborious and expensive. An Indian magnate, the Maha Rajah of Benares, intrusted to my friend, Mr. E. A. Reade, C.B., a sum of money to be employed for the benefit of the poor, on an object not of a religious character. He expended it on a well in the chalk, 358 feet deep, furnished with simple but most serviceable machinery for raising the water—large buckets, chains passing over iron sheaves, wound up by a winch and flywheel. Contrivances, such as a

C.—SECTION SHEWING THE WATER LINE IN A SERIES OF WELLS IN THE CHALK AT VARIOUS PERIODS, FROM MEASUREMENT.



Horizontal Scale . . 1 inch to 100 yards.
Vertical „ . . 60 feet to 1 inch.

The periods given are only by way of Example; if all the measurements were given, the whole space between the upper and lower line would be occupied, and so confused.

donkey-wheel, as shown at Carisbrook, are often used; but for a common well the simpler the machinery the better. Boring from the bottom of a chalk-well is sometimes resorted to with success; but it must be remembered that the water will not rise higher than the level at which it stands already in the well, though the bore-hole will quicken the supply. It is better, if the well has been made sufficiently deep, to enlarge the bottom in a bell-shape, or if a great quantity of water is required, to drive adits, if there seems no local reason to the contrary, in a direction *from* the known outfall of the water.

The upper greensand immediately underlies the chalk or chalk-marl. Its development is very irregular; in some places it attains the thickness of 140 feet; in other localities it is scarcely to be traced. Like the chalk, it freely absorbs the water falling on its surface: its water-bed is ruled as that in the chalk, but it is far more accessible; indeed there is no stratum where water is more regularly distributed or purer in quality. In sinking wells in this stratum care must be taken not to pierce the gault clay below, lest the quality of the water should be affected. The lower greensand is separated from the upper by the impermeable bed of gault clay: the lower greensand is permeable to water. Though the beds of which it consists vary considerably in their condition and in their capacity of absorption, sometimes a continuous water-level may be traced. It is often necessary to enlarge the bottom of the well to secure sufficient subterranean storage, as the wells, when exhausted, are slowly replenished. Very great care must be taken not, under any circumstances, to pierce the underlying Kimmeridge clay. If the Portland oolite underlies the greensand, and should the supply from the latter be insufficient, water may be sought in the oolite below, though the water of the greensand is usually of better and purer quality. When the Portland oolite overlies the Kimmeridge clay, the same caution will apply. Under no circumstances should the surface of the clay be pierced. There is a great similarity in all the oolitic strata as regards the supply of water, yet no strata present more difficulties and anomalies in the quantities yielded. This is to be attributed to the unequal thickness of the limestone and oolitic seams of rock, interlaced by beds of clay of most variable thickness and power of upholding water.

The Portland and coralline oolite are limited to a small area, and in many places consist merely of isolated patches, capping the surface of the Kimmeridge or Oxford clay. In such case the spot fixed on may materially influence the supply. In a known case it was desired to obtain water for a farmstead: a well was sunk to suit the convenience of the site, on which the buildings were to be erected; the water-supply was insufficient. It was pointed

out that the surface of the clay dipped in a certain direction, and that the well should be sunk near the margin of the oolitic rock in the direction of the dip. This was done, and water was obtained in abundance. This principle should be kept in view in seeking a supply of water throughout the oolitic range and the upper beds of the lias, where permeable beds rest on clay whose surface dips in a known direction. The presence of water under such circumstances is marked by the springs which issue from the hill-sides at the junction of these beds. The lower oolitic series, separated from the middle or coralline by the Oxford clay, which overlies the lias, is one of the principal water-bearing formations of England. Like the chalk, its surface is furrowed by frequent valleys, down which its waters find vent in perennial streams; though, unlike the chalk, its substance is interlaced with bands of clay of varying thickness, which throw out the water at every variety of level. These bands, besides the faults caused by disturbance, make it exceedingly difficult to determine the supply of water, and consequently the means which will afford the greatest facilities for obtaining it. It often happens that in one locality there are several distinct beds of water, either to be traced in wells, or to be seen, as indicated by springs issuing from the hill-sides. Such, for instance, is the case at Stonesfield, in Oxfordshire, where three distinct beds of water are found at various levels, at about 15, 50, and 100 feet from the surface respectively; none, except the lowest, which rests on the lias clay, yielding a large amount of water, but each sufficient for ordinary domestic purposes. The only obvious way of increasing the supply to the upper wells is the enlargement of the lower chamber, care being taken to avoid the hazard of sinking below the surface of the clay at the bottom. Agricultural drainage often decreases the subterranean supply to these strata; yet water running from the surface of the clays, which often cover large tracts, sometimes sinks by natural swallow or swilly holes into the permeable rock beneath, at the margin of the clay. These natural features might be assisted by simple artificial means to the increase of the supply to these strata.

Many of the valleys of this formation rest on upper lias clay. If, as in some cases, the base of the valley is the lower lias, the intervening marlstone, usually charged with water, adds another source of water to the district. Such valleys are well fitted for the storage of water, such as in the reservoirs which supply the summit-levels of the Oxford Canal, which have never yet failed. From the marlstone, as from the partings of clay in the oolite above, springs issue at so high a level above the foot of valleys, as to enable farmsteads, other establishments, and villages, to be supplied with water by gravitation, delivered through pipes or

open cuttings into troughs or tanks. Moreover the fall of water facilitates the use of hydraulic rams, by which reservoirs and whole establishments, as at Blenheim, Cornbury Park, Sarsden, and other places, are supplied with water at comparatively small cost. The delivery of water throughout the oolitic series favours the extension of this practice in a district where sinking for water through limestone and other rocks is an expensive process. It has been said that the marlstone intervenes between the upper and lower lias clays. This, if the lower beds of limestone or lias lime are excepted, is the only deep-seated source of water in the lias formation.

The new red sandstone, beneath the lias, which forms so large a portion of the surface of England to the west, contains large quantities of water; but much of it is excluded from ordinary uses by the mineral salts and impurities with which it is charged. The levels at which it is found in the upper marls or in the substance of the extensive sand-rock varies very much: in some cases the underground passage of the water is very free, in others very much confined. The exhaustion by mines is also a cause of disturbance to the supply. Though very many towns are supplied from deep wells in this stratum, where large quantities are required, as at Liverpool, recourse is had to storage at higher levels in the older formations, where rainfall is in excess and the physical features of the country favour this arrangement. The variable quantities and quality of the water, as ruled by the local geological condition of the new red sandstone, make it impossible to point out any rules except those which are suggested by local experience for increasing such supplies for agricultural or domestic purposes.

The increased rainfall, as well as the geological condition of the older formations, place the district to the west of the new red sandstone (as was suggested in the opening remarks) beyond the limit of this inquiry.

The writer, in revising the foregoing pages, finds that what he has said on a subject which has long engaged his attention has assumed the character of an essay on the water-supply of a great part of England rather than the specific point on which information was required; nevertheless, feeling the importance of the whole question, he has determined to submit this notice to the judgment of the Royal Agricultural Society.

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